

Comment on: “The Pioneer 6 Faraday rotation transients — On the interpretation of coronal Faraday rotation data” by Pätzold and Bird

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The detection of coronal streamers in Doppler scintillation measurements revealed for the first time that variations in radio occultation measurements near the Sun could be caused by quasi-stationary raylike structures [Woo et al. 1995]. This enlightened view has led to significant new information on the global morphology of coronal structures and their relationship to features in coronal and in situ solar wind measurements.

As observed in solar eclipse pictures, coronal streamers taper to narrow extensions or stalks of angular size $1\text{--}2^\circ$ with increasing heliocentric distance. Radio occultation measurements of these stalks have shown that they encompass the heliospheric current sheet, that the interplanetary counterpart of streamer stalks is the heliospheric plasma sheet, that streamer stalks comprise small-scale filamentary structures that are stronger and finer than those of the rest of the solar wind, and that the streamer stalks are the sources of the slow solar wind. These and other recent findings from radio occultation measurements have been discussed by Woo [1997] and Habbal et al. [1997].

Faraday rotation observations made with linearly polarized radio signals are unique amongst radio occultation measurements because they provide information on magnetic field in addition to density. It is through such measurements by Pioneer 6 [Levy et al. 1969] that the heliospheric current sheet has been found to be embedded in coronal streamer stalks [Woo 1997]. In the above-mentioned paper, Pätzold and Bird attempt to dismiss this important result. They perform path-integration calculations using assumed models of magnetic field and electron density, and point out that the calculated Faraday rotation falls short of the observed rotation by Pioneer 6. We show here that their analysis and claims have no merit.

Inverting Faraday rotation measurements through modeling to obtain meaningful information on magnetic field and electron density is practically impossible. First, our knowledge of magnetic fields near the Sun is poor because of the lack of measurements. Second, although there are problems with the uniqueness in the interpretation of all path-integrated measurements, the case of Faraday rotation measurements is particularly difficult. Faraday rotation depends not only on the magnitude but also the direction of the component of magnetic field along the radio path. As an example, the magnetic field could be very strong and still produce little Faraday rotation if there are opposing components along the radio path. Disentangling magnetic field and electron density in the case of the Pioneer 6 Faraday rotation measurements is also exacerbated by the absence of independent information on density that could have been provided by simultaneous ranging measurements.

A closer look at the analysis presented in the above-mentioned paper illustrates the futility of modeling Faraday rotation. Overlooking the obvious difficulties in estimating magnetic field reliably due to a lack of measurements, we concentrate on electron density mainly because it has been observed extensively both in white-light and radio measurements. In the above-mentioned paper, Pätzold and Bird apply a recently published density model [Pätzold et al. 1997] for coronal streamers deduced from 1991 Ulysses ranging measurements to the Pioneer 6 observations. There are fundamental reasons why this streamer model is pointless and irrelevant.

First, ranging measurements necessarily take place at different heliocentric latitude, longitude and distance, and thus observe different structures. Even if temporal variations are ignored, attempting to model the radial variation of a structured corona using measurements of a moving 'point' in the plane of the sky while the Sun rotates underneath it (as opposed to using an image such as that in white-light) is far-fetched, and leads to erroneous conclusions [Woo 1996].

Second, defining the solar wind region within $\pm 20^\circ$ of the heliospheric current sheet as the 'streamer belt', and assigning one density value to it at a fixed radial distance makes little sense for a region of steep density gradients revealed by both ranging [Woo and Habbal 1997] and white-light measurements [Guhathakurta et al. 1996, Wang et al. 1997]. White-light measurements show that beyond 3 R_o path-integrated density falls by at least an order of magnitude across the streamer stalk and within about $\pm 20^\circ$ of the heliospheric current sheet [Wang et al. 1997]. Any significance that the 'streamer belt' region may have is lost in the process of measuring it. Unlike the case of extensive white-light measurements, the sparse 1991 Ulysses ranging measurements are incapable of adequately observing it. Not only do the Ulysses ranging measurements hopelessly undersample the transverse profile of the 'streamer belt,' there are only five measurements to define the radial variation inside 11 R_o where the Pioneer 6 Faraday rotation events were observed. Locating the 'streamer belt' itself is subject to considerable uncertainty, since it is referenced to the heliospheric current sheet, a feature that is not determined by measurement, but is inferred from potential field calculations.

Based on the density model calculations alone, it is not surprising that estimates of Faraday rotation in the above-mentioned paper fall short of the rotation observed by Pioneer 6. Since the sparse 1991 Ulysses ranging measurements undersample the 'streamer belt,' they underestimate its density. Of more serious consequence is the application of the 'streamer belt' densities to the Faraday rotation calculations of the Pioneer 6 streamer stalks. While the 'streamer belt' comprises the region within $\pm 20^\circ$ of the heliospheric current sheet, streamer stalks roughly correspond to the region within $\pm 1^\circ$ of the heliospheric current sheet. It is clear that this incorrect application of the irrelevant 'streamer belt' density model to the Pioneer 6 streamer stalks produces significantly lower Faraday rotation estimates for them.

In the above-mentioned paper, Pätzold and Bird express their difficulty in understanding how the short duration Pioneer 6 events can be caused by solar rotation of a

radial structure such as a streamer stalk. Short duration streamer stalk crossings have been confirmed by simultaneous radio occultation and white-light measurements [Habbal et al. 1997]. A striking demonstration of how this happens on a more global scale is evident from a recent study of streamer structure made with the LASCO white-light coronagraph [Wang et al. 1997]. When the heliospheric current sheet is tilted, as in the case of the Pioneer 6 observations, it gives rise to individual structures that move in latitude in the plane of the sky as they rotate with the Sun. This projection effect shows up in white-light synoptic maps as wispy arc-like features that curve away from the equator. The low-latitude Pioneer 6 observations most likely crossed these features.

Finally, although offering no evidence, Pätzold and Bird suggest that the Pioneer 6 Faraday rotation events represent CMEs rather than coronal streamers. Signatures of CMEs in radio occultation measurements are distinctly different from those of coronal streamers [Woo 1997]. The signatures of the observed Pioneer 6 Faraday rotation and spectral broadening events are unmistakably those of streamers. Both events return to their pre-transient levels after approximately 2 hours, consistent with a structure that is $1-2^\circ$ in angular size and rotates with the Sun. Both exhibit symmetry about their centers, consistent with the symmetry of the heliospheric current sheet. In contrast, the time histories of both spectral broadening and Faraday rotation measurements for CMEs lack symmetry and do not typically return to their pre-transient levels for at least 8 hours. Recent studies [Woo 1997] discuss their relationship to the signatures of CMEs observed in in situ plasma measurements near earth.

In conclusion, the arguments presented in the above-mentioned paper by Pätzold and Bird, dismissing the coronal streamer interpretation of the Pioneer 6 Faraday rotation measurements, suffer from a lack of understanding of both the structure of streamers and CMEs near the Sun and their corresponding signatures in radio occultation measurements. There is also a failure to realize the severe inherent limitations of the use of radio occultation measurements to model the three-dimensional distributions of electron density and magnetic

field. The calculations of Faraday rotation based on the 'streamer belt' model of Pätzold et al. [1997] illustrate the futility of this type of modeling. The assumed constant density in the 'streamer belt' is an oversimplification of the density distribution of the highly structured coronal streamers where steep gradients are found. Making matters worse, the 'streamer belt' has been inadequately determined by the sparse 1991 Ulysses ranging measurements, and it has been further erroneously applied to coronal streamer stalks, resulting in significant underestimation of Faraday rotation for the Pioneer 6 observations. By contrast, the interpretation of the Pioneer 6 Faraday rotation events as coronal streamer stalks crossing the radio path [Woo 1997] is based on the known existence of stalks from white-light and spectral broadening measurements, the known signatures of streamer stalks and CMEs in spectral broadening measurements, and most significantly, does not depend on the unnecessary and ambiguous inversion of the Faraday rotation measurements.

Pätzold et al. [1997] have also inferred a solar wind speed profile from the 'streamer belt' density profile. It comes as no surprise that, since the speed profile is based on an ill-defined and ill-determined density model, the acceleration profile would be similar to the velocity profile based on solar wind velocity measurements that do not distinguish solar wind types (see Fig. 2.18 of Bird and Edenhofer [1990]). Density models such as the 'streamer belt' model serve only to confuse, mislead and deter from the significant results that can be inferred from ranging measurements made by the NASA Deep Space Network. The strength in these ranging measurements lies in their ability to detect small changes in low levels of path-integrated density across coronal structures, and it is this unique feature that has led to the recent findings that plumes or polar rays are not confined to polar regions, and that the polar coronal hole boundary extends radially into interplanetary space [Woo and Habbal 1997].

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